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Monte Carlo simulations of the luminosity function of hot white dwarfs

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Abstract. We present a detailed Monte Carlo simulation of the population of the hot branch of the white dwarf luminosity function. We used the most up-to-date stellar evolutionary models and we implemented a full description of the observational selection biases. Our theoretical results are compared with the luminosity function of hot white dwarfs obtained from the Sloan Digital Sky Survey (SDSS), for both DA and non-DA white dwarfs. For non-DA white dwarfs we find an excellent agreement with the observational data, while for DA white dwarfs our simulations show some discrepancies with the observations for the brightest luminosity bins, those corresponding to $L \gtrsim 10 L_{\odot}$.

1. Introduction

Among other applications — see, for instance, the recent review of Althaus et al. (2010) — the luminosity function and space density of white dwarfs provide interesting constraints on the local star formation rate and history of the Galactic disk in the Solar neighborhood. However, to address these questions a large white dwarf sample of known completeness is required. The SDSS has provided us with such a sample, and from it a reliable white dwarf luminosity function for hot white dwarfs has been recently obtained (Krzesinski et al. 2009). This white dwarf luminosity function has the interesting particularity that it has been obtained using solely spectroscopically-confirmed white dwarfs from the SDSS DR4, and thus constitutes an excellent testbed to check not only the white dwarf cooling sequences at high luminosities, but also our ability to model reliably some Galactic inputs necessary to compute the luminosity function. Here we describe the results of a comprehensive set of Monte Carlo simulations aimed to model the hot part of the white dwarf luminosity function for both DA and non-DA stars.

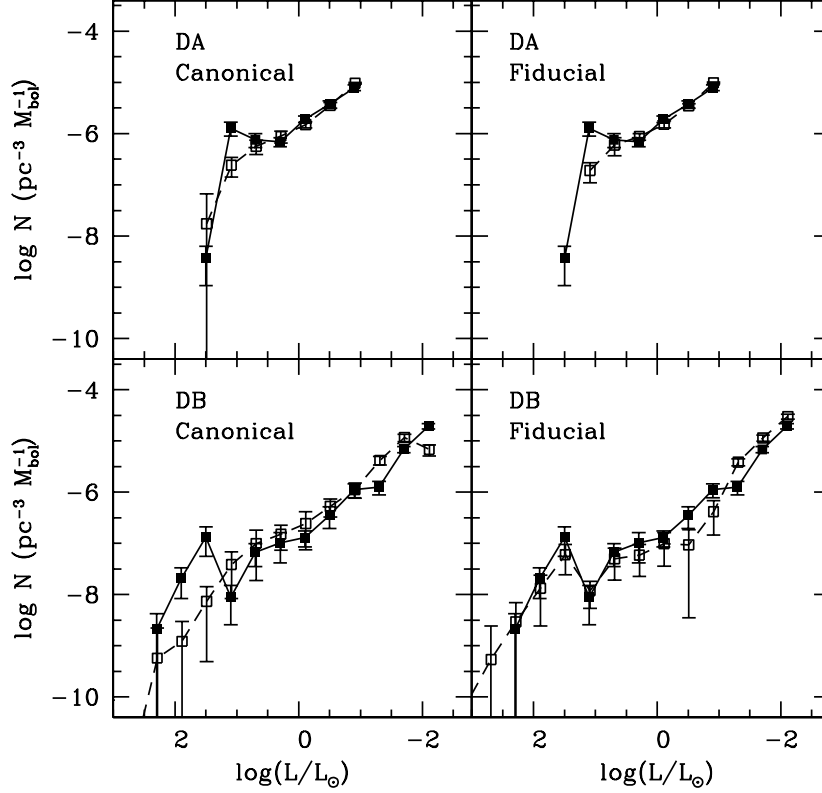


Figure 1. White dwarf luminosity functions for hot DA and DB white dwarfs for two different models. The solid line is the luminosity function of Krzesinski et al. (2009), while the dashed line shows the result of our simulations.

2. The Monte Carlo simulator

We simulated a synthetic population of disk white dwarfs in the Solar neighborhood in a sphere of 3 kpc. An extensive description of our Monte Carlo simulator can be found in previous papers (García-Berro et al. 1999; Torres et al. 2002; García-Berro et al. 2004). Thus, here we only summarize the most important inputs. We adopted a disk age of 10.5 Gyr, a constant star formation rate and a standard initial mass function (Kroupa 2001). Velocities were obtained taking into account the differential rotation of the Galaxy, the peculiar velocity of the Sun and a dispersion law which depends on the Galactic scale height. A double exponential profile was used, with a scale height $h = 250$ pc and a scale length $L = 1.3$ kpc. Also, the initial-final relationship of Catalán et al. (2008) was adopted. The cooling sequences employed depend on the mass of the white dwarf, M_{WD} . If $M_{\text{WD}} \leq 1.1 M_{\odot}$ a CO core was adopted, while if $M_{\text{WD}} > 1.1 M_{\odot}$ an ONe core was used. In the case of CO white dwarfs with H-rich envelopes we used the evolutionary calculations of Renedo et al. (2010), while for white dwarfs with ONe cores we used those of Althaus et al. (2007). For H-deficient white dwarfs we used the cooling sequences of Benvenuto & Althaus (1997), which correspond to pure He atmospheres, and the bolometric corrections of Bergeron et al. (1995). Finally, we used the same selection criteria employed to cull the observational

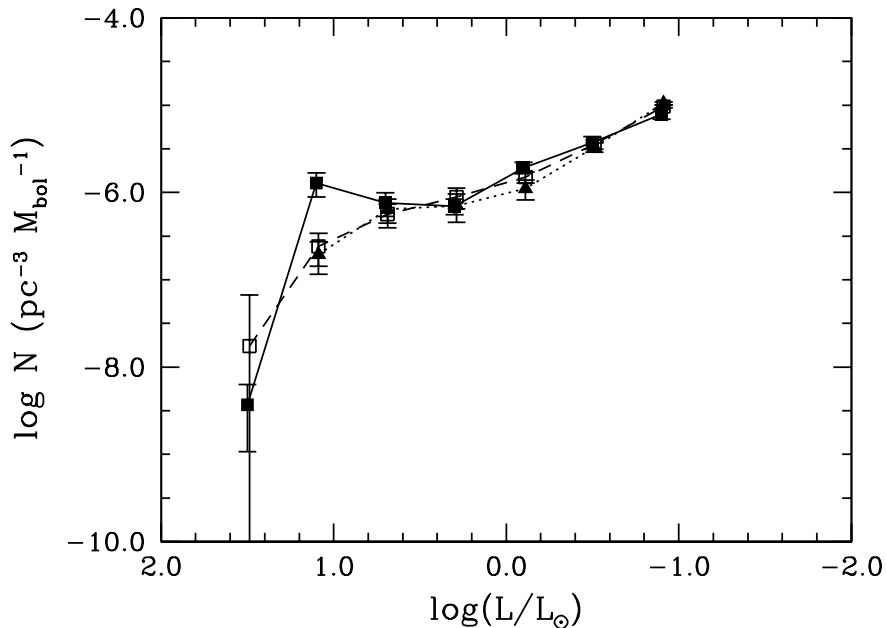


Figure 2. White dwarf luminosity functions for hot DA white dwarfs and different assumptions. The solid line is the luminosity function of Krzesinski et al. (2009), the dashed line shows our fiducial model, while the dotted line represents the luminosity function when NLTE corrections and metal contamination is considered.

sample of Krzesinski et al. (2009). Specifically, only white dwarfs with $g > 14$ and a fully de-reddened magnitude $g_0 < 19$ were selected, whereas the color cuts were $-1.5 < (u - g)_0 < 0$ and $-1.5 < (g - r)_0 < 0$.

3. Results

In Fig. 1 we show several model luminosity functions for hot DA and DB white dwarfs for two different assumptions. In the canonical model we adopt a DA/DB ratio $f_{\text{DA/DB}} = 0.80$, independently of the effective temperature. In a second simulation $f_{\text{DA/DB}}$ depends on T_{eff} , as obtained from the SDSS (Krzesinski et al. 2009). The solid lines represent the luminosity function of Krzesinski et al. (2009), while the dashed lines show our simulated luminosity functions. The upper panels of Fig. 1 show that the luminosity function of hot DAs barely depends on the DA/DB ratio, whilst that of non-DA white dwarfs depends sensitively on it. Also, it is clear that the agreement with the observational data is excellent for the model in which the DA/DB ratio depends on T_{eff} . Thus, we adopt this model as our fiducial one.

One puzzling characteristic of the observational luminosity function of hot white dwarfs is the existence of a plateau at luminosities around $\log(L/L_{\odot}) \approx 1$. In a first attempt to explore its origin, we analyzed the effects of NLTE corrections and of metallicity. We adopted the NLTE corrections of Napiwotzki et al. (1999) for temperatures

30,000 K < T_{eff} < 100,000 K and gravities $6.50 < \log g < 9.75$. Additionally we assumed that 50% of hot DA white dwarfs have metals in their atmospheres. This implies that their effective temperature is overestimated by 20% at 80,000 K and 0% at 40,000 K. The results are shown in Fig. 2. The dashed line corresponds to our fiducial model and the dotted line to the model in which both NLTE corrections and metal contamination have been included. Clearly, these additional effects have a small impact on the computed luminosity function.

Finally, to assess if the plateau of the luminosity function of hot DAs could correspond to a recent burst of star formation (Noh & Scalo 1990), we computed several luminosity functions with different burst strengths occurring at various ages. However, we found that for the approximate age of a typical white dwarf of $0.6 M_{\odot}$ at $\log(L/L_{\odot}) \approx 1$, the burst should have occurred very recently. Thus, there are only two possible alternatives left. Either the theoretical cooling models are not entirely reliable at these luminosities — possibly influenced by the initial conditions — or, instead, since at this luminosity the number of objects is relatively small the observational error bars inherent to the $(1/V_{\text{max}})$ method have been underestimated (Geijo et al. 2006), and the plateau corresponds to a statistical fluctuation.

4. Conclusions

We presented a set of simulations of the luminosity function of hot white dwarfs. Our results are in excellent agreement with the observations for DB stars, while the plateau of the luminosity function of DAs at $\log(L/L_{\odot}) \approx 1$ cannot be reproduced. At these luminosities NLTE effects and metal contamination play a minor role in shaping the luminosity function, and the plateau cannot be explained by a burst of star formation. Thus, it could be due to a failure of the cooling models or to a statistical fluctuation.

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